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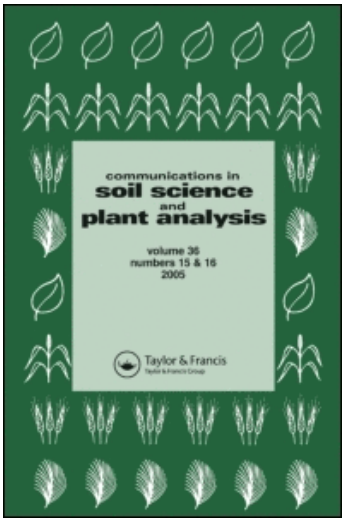

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Effect of a Temporal Carbon Gradient on Nitrogen and Phosphorus Dynamics and Decomposition During Mesophilic Composting

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Effect of a Temporal Carbon Gradient on Nitrogen and Phosphorus Dynamics and Decomposition During Mesophilic Composting

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Abstract: Excess carbon (C) can immobilize inorganic nitrogen (N) and phosphorus (P) when composting manure and has been used to reduce the moisture content of liquid manure so they can be composted. A mesophilic composting strategy was previously developed and shown to be an effective method to manage liquid manure without the need for excess C. The objective of this study was to determine if a temporal C gradient would sequester more N and P without the need for excess C. The experiment was conducted in bags. All treatments had arctic char manure applied at the same rate (1.28 g N), every 14 days for 112 days. The C source, ground corn stover, was applied in three batch sizes. The 1X treatment applied 70 g of corn stover every 14 days, the 4X treatment applied 280 g of corn stover at days 0 and 56, and the 8X treatment applied 560 g of corn stover once at day 0. All bags had the same amount of C and N added to them by the end of the experiment at a C : N ratio of 30 : 1. As the C to N or P ratio decreased below 20 and 30, respectively, net mineralization occurred, and the time of this occurrence was similar for all C treatments. The concentration of N and P were relatively low until day 91 when NH_4-N and P and day 105 when NO_3-N started to increase, after which point mineralization occurred at a rate of about 60 mg N and 4 mg P/kg mass/day. Because the temporal C gradient was not in phase with mineralization, it was not effective at immobilizing N and P. Spatial separation of high carbon zones through layering manure and the

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carbon source may be an effective way to maintain a long-term C gradient and capture leaching N and P while minimizing C inputs.

Keywords: Compost, nitrogen, phosphorus, manure, aquaculture, fish

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INTRODUCTION

Although storage and land application of liquid manure has a long history of being an effective and practical technology, because it cannot occur year round, anaerobic storage is a necessary component of the whole system. Composting increases the value of manure and can be a practical system alternative to storage in a lagoon, giving the farmer more flexibility in time of application. Currently, manure from fish grown in raceway systems is settled and stored in basins. During storage, phosphorus and other nutrients are continually released from the manure into the surrounding water in the basin. Because of how manure is managed on farms, water flows through these basins daily carrying these released nutrients to surface water. Adler and Sikora (2004, 2005) developed a layered mesophilic compost system that allows the manure to be stored and treated on land after it has been settled in the basins, greatly reducing the potential discharge of phosphorus to surface waters.

Composting high moisture content manure is a challenge. Fish manure typically has a solids content of about 2–10% after initial primary treatment, and for thermophilic composting, the moisture content of the compost mixture needs to be reduced to below 60% (Willson et al. 1980; Rynk 1992). Compost with a high-moisture content (>60%) can readily cause development of anaerobic conditions leading to generation and release of odors. Where excess moisture is not a concern, carbon is added to meet microbial process needs, a C : N ratio of about 25. At a solids content of 2–10%, achieving the target of 60% moisture content would require 2–10 times more carbon than a C : N ratio of 25. Mesophilic composting of high liquid content manures does not require excess C to reduce its water content as is needed with thermophilic composting because oxygen demands are lower, and the layer that has the highest requirement for oxygen is near the surface (Adler and Sikora 2005) where oxygen transfer is rapid. Carbon is added only to meet microbial needs to stabilize the manure rather than adding the excess needed to produce an aerobic environment.

The chemical composition affects the decomposition rate of all organic matter including crop residues (Kumar and Goh 2000; Martens 2000; Trinsoutrot et al. 2000), compost (Tiquia et al. 2002), and manure (Gordillo and Cabrera 1997). As organic matter decomposes, N and P are mineralized (Tian et al. 1992). Compost stabilizes as the organic matter decomposes, and the mineralized N and P can be lost to the environment because of

volatilization [as ammonia (Hong et al. 1998; Elwell et al. 2002) and nitrous oxide (Czepiel et al. 1996; Hao et al. 2001), leaching (Eghball and Power 1997; Sommer 2001), and runoff (Tiquia et al. 2002; Eghball et al. 1997)].

The C : N or C : P ratio affects the net mineralization rate of N or P, respectively. Net immobilization of N and P occurs when the C : N ratio is greater than 30 and the C : P ratio is greater than 300 (Stevenson and Cole 1999). Excess C has been used to immobilize inorganic N in soil (Baer et al. 2003). Adding excess C to compost may reduce the loss of N and P but would be an extra cost to the enterprise. A temporary state of excess C may significantly immobilize nutrients for critical periods. The objective of this study was to determine if a temporal C gradient would sequester more N and P without the need for excess C in the long term.

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MATERIALS AND METHODS

The experiment was conducted in 30 × 61-cm polypropylene bags, 3 bags per treatment, at about 15°C. Arctic char (*Salvelinus alpinus*) manure (ACM) was applied at the same rate (1.28 g N) to all C treatments, every 14 days, with day 98 being the last time of application. The carbon source, corn stover (*Zea mays*) ground to pass a 2-mm-mesh screen, was applied in three batch sizes. The 1X treatment applied 70 g of corn stover every 14 days, the 4X treatment applied 280 g of corn stalks at days 0 and 56, and the 8X treatment applied 560 g of corn stalks once at day 0. On the farm, the temporal carbon gradient could be established by either mixing in the appropriate amount of ground corn stalks and ACM each time or adding C in excess of C : N 30 initially and just adding ACM each time until a C : N 30 was reached and then repeating the cycle by adding excess C again. All bags had the same amount of carbon and nitrogen added to them by the end of the experiment at a C : N ratio of 30 : 1.

The percent ash and carbon, and the amount of nitrogen, ammonium, nitrate, and phosphorus were determined. Sampling occurred 17 times beginning on days 1, 7, and then every 14 days (7 days after each application) until day 203; the last sample was taken on day 273. The samples were dried at 105°C to a constant weight, ground through a 20-mesh (0.85 mm) screen in a Wiley mill. The percent ash was determined by heating the samples at 550°C for 24 h (APHA 1992). The percent carbon was calculated from the percent ash [(100%ash)/1.8] (Rynk 1992). Total N was determined with a FP-428 LECO nitrogen determinator (TMECC 4.02-D, 2002) (LECO Corporation, St. Joseph, MI). Total P was determined by digesting the samples with $HClO_4$ (Adler 1995) followed by measurement of the P concentration (Murphy and Riley 1962). Duplicate samples were taken and stored frozen (−20°C) for subsequent analysis of ammonium, nitrate, and water-extractable P. Ammonium and nitrate were extracted by shaking 2.5 g of compost with 25 mL of 2 *M* KCl for 1 h in 50-mL graduated conical-bottom polypropylene

centrifuge tubes on an end-over-end shaker, centrifuged (3570 × G for 15 min), and a subsample of supernatant was analyzed (Mulvaney 1996). Water-extractable P was determined by shaking 1 g of compost with 25 mL of double deionized water in 50-mL graduated conical-bottom polypropylene centrifuge tubes for 1 h (Kuo 1996) on an end-over-end shaker, centrifuged (3570 × G for 15 min), and a subsample of supernatant was analyzed (Murphy and Riley 1962).

RESULTS AND DISCUSSION

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The compost appeared to be reaching stability as indicated by the CNP concentrations approaching constant values. The rate of decrease in percent C and increase in percent N and P decreased and was leveling off after about 160 days (Figure 1). The percent C decreased from about 51 to 37% (an 80% reduction in g C/g ash). Others have observed a range of mass reduction from 18 to 80% as the compost stabilizes (Rynk 2002). Because of the temporal C gradient at day 0, the concentration of N and P varied with treatment, but the percent N leveled out at about 3.5% and the percent P at about 1.9% as the compost became more stable (Figure 1). This is a similar pattern found in decomposition of all organic matter; C decreases and N and P increase along with other components of the ash, although some ash components, such as N, can be lost because of volatilization, leaching, or runoff.

As the compost stabilized, the ratios of CNP followed a similar pattern as their individual concentrations. The initial ratios were variable due to the C gradient but decreased to a similar value (Figure 1). The C : N ratios started out at about 30, 47, and 56 for the 1X, 4X, and 8X treatments, respectively, but all decreased to about 10.5. The C : P ratios started out at about 59, 154, and 259 for the 1X, 4X, and 8X treatments, respectively, but all decreased to about 21.7. The N : P ratios started out at about 2.0, 3.3, and 4.6 for the 1X, 4X, and 8X treatments, respectively, but all decreased to about 1.9. The N : P ratio of the 1X treatment was relatively constant, indicating that N and P were not lost from the system. The N : P ratio in the 4X and 8X treatments decreased as ACM was added, reaching the value of the 1X treatment when the quantities of AMC and corn stover were the same between all the treatments. The CNP ratios decreased with all treatments due to decomposition and loss of C over time. The decrease of CNP ratios was more rapid with the 4X and 8X treatments than the 1X treatment because N and P were added from ACM to the compost mixture. The CNP ratios reached at stability will depend on the resistance of the C source to decomposition and the initial N and P concentrations, among other factors. When manure is added during composting, the final N and P concentrations are typically higher than when decomposition of the C source occurs without the added N and P. The C content was higher and N and P contents lower in the corn

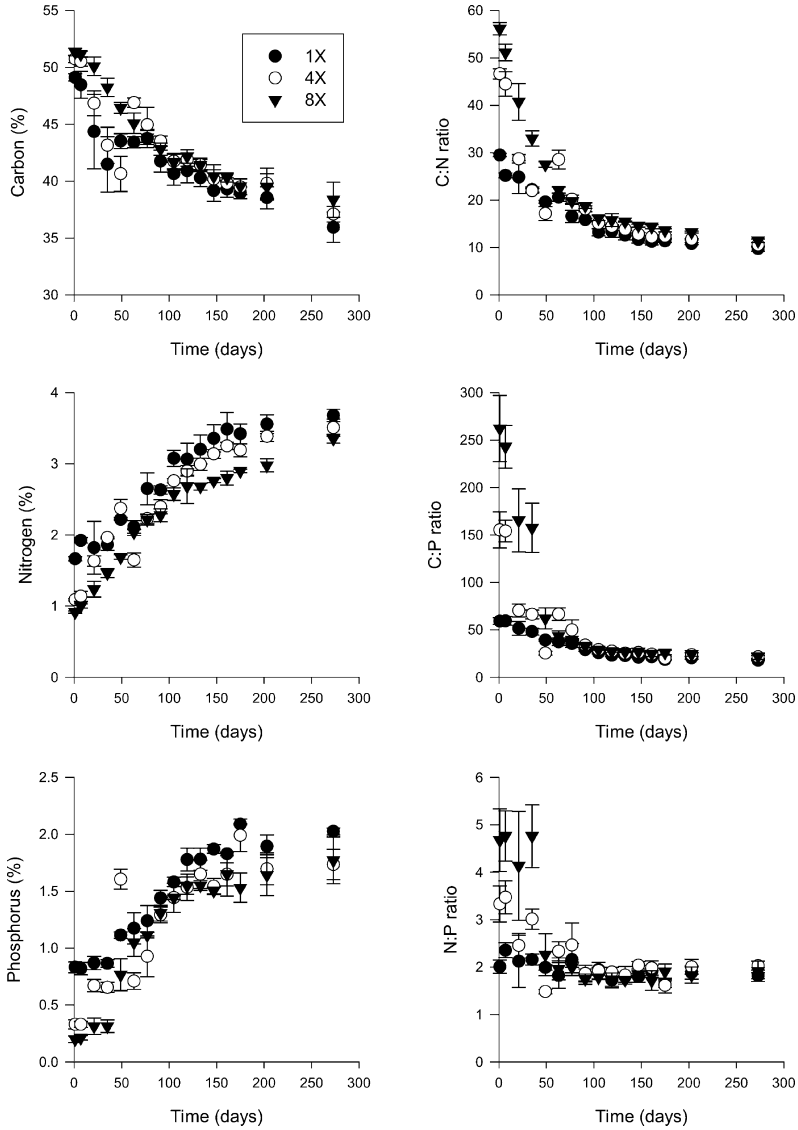

Figure 1. Change in content and ratios of carbon, nitrogen, and phosphorus in compost over time made from arctic char manure applied over a temporal carbon gradient with corn stover from 1X with a C : N ratio of 30 to 8X with the highest initial excess carbon content. Vertical bars denote $\pm$SD (n = 6).

stover than in the ACM. The initial CNP concentrations of the materials were 52.5-C, 0.77-N, 0.14-P% in corn stover and 37.9-C, 5.70-N, 0.81-P% in ACM. Animal manures contain different amounts and forms of N (Cabrera and Gordillo 1995) and P (Sharpley and Moyer 2000).

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Inorganic N and P concentrations in the compost increased as the CNP ratios dropped below threshold values. Net mineralization of N and P occurred as the C : N or C : P ratio decreased below 20 and 30, respectively (Figure 2), and the time of this occurrence was similar for all C treatments. The findings of this study on N mineralization were similar to previous work. Most authors have found that net N mineralization of residues occurs when the C : N ratios are less than 25 (Paul and Clark 1996). With a C : N ratio of 20–30, water-soluble N should be minimized (Stevenson and Cole 1999), as was also observed in this study, and leaching losses minimal. The C : P ratio where P mineralization occurred appeared to differ from previous studies with mineralization occurring around 30 vs. 200. Water-soluble P can be sequestered by having a higher C : P ratio. Net immobilization of P occurs when the C : P ratio is greater than 300 and net

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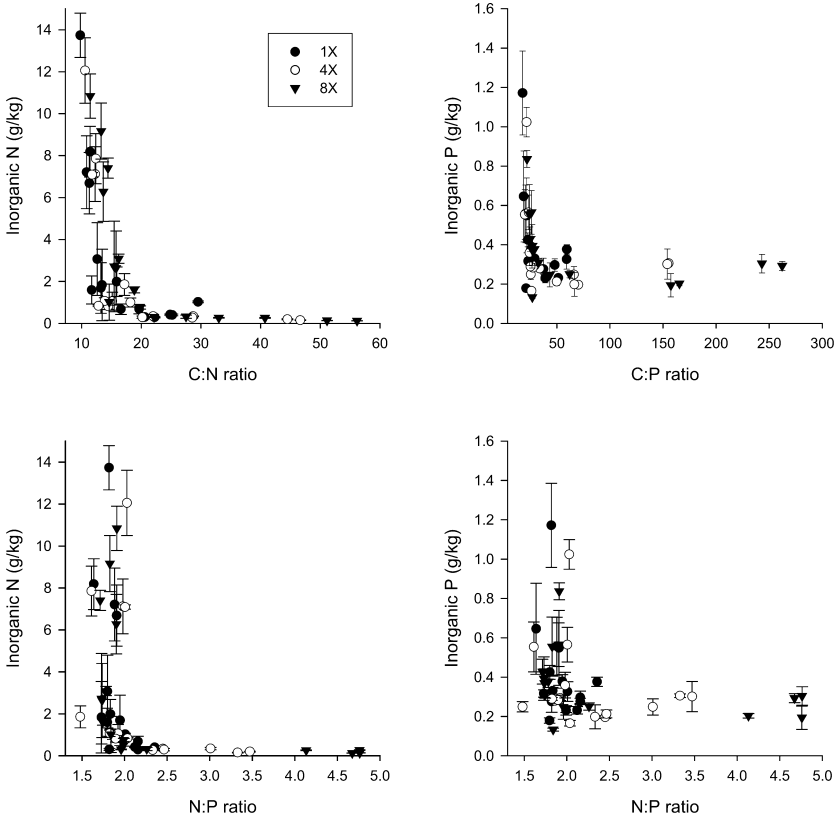

Figure 2. Relationship of inorganic nitrogen and phosphorus mineralization to the ratio of carbon, nitrogen, and phosphorus. Compost was made from arctic char manure applied over a temporal carbon gradient with corn stover from 1X with a C : N ratio of 30 to 8X with the highest initial excess carbon content. Vertical bars denote $\pm$SD (n = 6).

mineralization when less than 200 (Stevenson and Cole 1999). Although organic matter decomposition has a significant impact on P cycling in soils (Gressel and McColl 1997), inconsistency in use of the C:P ratio as an index of immobilization or mineralization may possibly be due to a variable amount of inorganic P in organic materials, presence of limiting nutrients (e.g., N and S), and quality of the carbon (Dalal 1977). Inorganic N and P concentrations were low when the N:P ratio was greater than 2 (Figure 2).

Phosphorus content and form varies in compost. Although the inorganic fraction of total P is consistently high in composts, about 70–95 + % (Traore et al. 1999; Sharpley and Moyer 2000; Frossard et al. 2002; Eghball 2003), the fraction of total inorganic P, which is water-extractable, range from being relatively low 1–12% (Frossard et al. 2002; Eghball 2003; Leytem et al. 2004; Adler and Sikora 2005) to high 15–40% (Sharpley and Moyer 2000; Eneji et al. 2003). Water-extractable P ranged from about 0.2 to 1.2 g/kg (Figure 3), similar to those measured in other studies (Traore et al. 1999; Sharpley and Moyer 2000; Frossard et al. 2002; Eghball 2003; Eneji et al. 2003; Leytem et al. 2004; Adler and Sikora 2005). In this study, both inorganic N and P increased with time (Figure 3). However, Adler and Sikora (2005) observed that although inorganic N increased, water-extractable P decreased as the organic matter decomposed. Others have also observed a decrease in water-extractable P over time with different types of composts (Traore et al. 1999). When P was fractionated, it was found that other forms of inorganic P such as HCl-soluble P increased and water-extractable P decreased (Traore et al. 1999; Eneji et al. 2003). This trend suggests the possible transformation of water-extractable P to more stable forms, which would reduce the potential for runoff losses.

The concentration of N and P were relatively low until day 91 when NH_4-N and P and day 105 when NO_3-N started to increase (Figure 3), after which point mineralization occurred at a rate of about 60 mg N and 4 mg P/kg mass/day. This higher mineralization rate of N than P led to about 34% of the N being mineralized after 39 weeks, whereas only about 6% of the P had mineralized (Figure 3). These N mineralization rates were similar to those found with ACM and wheat straw (Adler and Sikora 2005), and the increase in rate of mineralization occurred during a similar time frame even though the C:N ratio was much lower throughout the study. Inorganic N and P are more readily lost to the environment and, therefore, loss of N appears to be of more concern than P in mesophilic compost because it had mineralized at a much greater rate. In a previous study, Adler and Sikora (2005) found that water-extractable P did not increase with time even though the C:P ratios were low.

The chemical composition of organic matter has been shown to affect the rate of decomposition. Some C sources are more resistant to decomposition (e.g., woody biomass) than others and so have slower rates of decomposition and higher levels of C when compost is stable. Organic matter quality decreases as C:N ratio, lignin, and polyphenol content increase (Harborne

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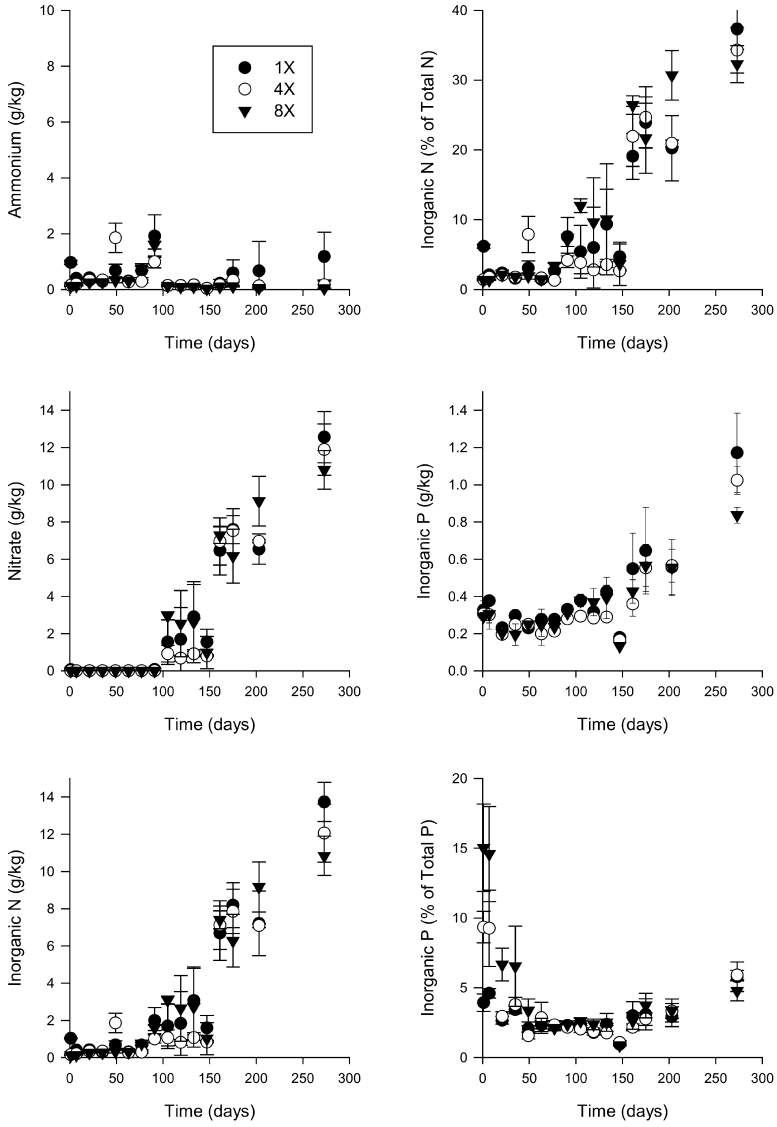

Figure 3. Changes in inorganic nitrogen and phosphorus mineralization over time. Compost was made from arctic char manure applied over a temporal carbon gradient with corn stover from 1X with a C:N ratio of 30 to 8X with the highest initial excess carbon content. Vertical bars denote $\pm$SD (n = 6).

1997; Heal et al. 1997; Northup et al. 1998, 1999; Kumar and Goh 2000). Chemical composition of corn stover was lignin (7.8%), cellulose (48%), and hemicellulose (28.1). Decomposition of crop residues is often suppressed at C:N ratios above about 20–30 (Kumar and Goh 2000). Many studies have

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observed that lignin decreases the decomposition rate and nutrient release and has also been shown to increase N immobilization (Aber et al. 1990; Tian et al. 1992). The decomposition of plant residues is best predicted by combining C:N ratio, lignin, and polyphenol, and carbohydrate content (Tian et al. 1995). Crop residues tend to be higher quality and decompose more rapidly than many plant residues due to higher quality (Tian et al. 1992; Kumar and Goh 2000).

Composting manure typically requires the addition of a C source either to meet microbial process needs or reduce the moisture content of the mixture to help maintain aerobic conditions. A mesophilic composting strategy was previously developed by Adler and Sikora (2005) and shown to be an effective method to manage liquid manure without the need for excess C to reduce its moisture content. Excess C during composting can be an effective strategy to immobilize N and P. However, reducing inputs is important to reducing system costs. For the temporal C gradient described in this article to be effective, it needs to be in phase with the mineralization of N and P. In this study, mineralization occurred after the CNP input ratios were similar between all C treatments and, therefore, not effective in immobilizing N and P. Spatial separation of high carbon zones to capture leaching nutrients may be a way to maximize the efficiency of carbon use. This spatial C gradient could be achieved by layering the C and manure applications as was previously done by Adler and Sikora (2005). When the liquid manure was applied to the C layer, it created a C gradient as the C layer surface captured most of the manure and the concentration decreased with depth of the C layer.

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